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PEAT DEPOSITS AND THEIR EVIDENCE OF CLIMATIC CHANGES

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(WITH TWELVE FIGURES)

The time in which the various peat deposits of the United States were formed can be determined only from a joint consideration of glacial geology, climate, and plant remains. These reflect the relations between a deposit of peat materials and its environment. To attempt a correlation of this kind on a chronological basis, however, has many difficulties, which investigators in the respective sciences appreciate.

The essential nature of stratigraphic differences in peat deposits is indicated by the nature of the plant remains and the order in which layers of peat material lie upon one another, that is, by the sequence of the vegetation units which at one time formed layers of plant remains in the deposit. As to the tectonic order of the layers or series of layers of material composing a peat deposit, little need be said at this time. From the standpoint of stratigraphy the condition of the initial area in which a pioneer plant population established itself is the critical factor of greatest importance, so far as the beginning of the course of development is concerned. The sequence of the development may become changed anywhere in the course, either by changes in environmental factors or in plant population. These changes are all recorded within the deposit. In the vast majority of peat deposits the beginning of

development and the succession of peat materials have to do with the factor of water content in the original area. Usually the quantity of water is more frequently concerned than its salinity, acidity, or alkalinity. The initial water relation, by its selective action, determines not only the characters of the life forms which establish themselves as the pioneer population, but also the number of layers possible and the order of their sequence.

In a preceding paper (7) it was proposed to classify peat deposits of whatever nature into two great primary groups, the group of water-laid peat deposits and the group of land-laid peat deposits, in accordance as they have arisen in water or on partly drained but relatively moist initial areas. In the water-laid peat deposits the bottom layers consist of materials which accumulate only in standing water. They contain the remains of planktonic organisms and macerated material from plants more or less submerged or floating, or which occupied the margins of the basin. Subdivisions of this group are given in the section which follows. In the land-laid group of peat deposits the origin is indicated in the mineral substratum by the vertical roots of plants which at one time occupied the area, as a well defined plant population or vegetation unit. The general stratigraphic subdivisions in this group are indicated by the order in which the vegetation units invaded and occupied the land area. With respect to the layers of peat material formed by them the order may be (1) progressive, that is, beginning with some member of the marsh group of peat materials until the deciduous or coniferous forest climax of the region is reached; (2) stabilized, that is, it may begin and continue in a stable forest climax; or (3) the order may indicate the conversion of the basal forest climax into marsh and finally to open water conditions by the influence of various environmental causes. This distinction between the two primary groups of peat deposits is clear cut, and is readily made in field work. The only possible difficulty arises when the plant remains have been redeposited or partially removed by any later action, such as erosion. Even secondary disturbances of this nature, however, do not invalidate the importance of the stratigraphic viewpoint. Its significance for correlation studies has been sufficiently dwelt upon elsewhere (6).

The following peat deposits are representative of the subdivisions in the land-laid group, and will be reported in another paper: 1. The New Haven Marsh near Plymouth, Ohio (glacial Lake Maumee type); the peat deposit southwest of Rome, New York (glacial Lake Iroquois type); and the Algoma Muskeag near Roseau, Minnesota (glacial Lake Agassiz type). 2. The Dismal Swamp west of Norfolk, Virginia (Pamlico coastal terrace type). 3. The Kankakee Marsh, between South Bend and Crumstown, Indiana (in the Bloomington morainic system). It will be noted that peat deposits are regarded here in their relative space and time dimensions.

In regard to the stratigraphic units of peat deposits, reference may be made to Bulletin 802 (5) and left with this passing suggestion. Whatever system of classification of peat materials may be adopted, it will be found that for several reasons it cannot be carried uniformly and with constant value over so broad a territory as discussed here. The main difficulty arises from the unlike development of the vegetation unit which forms the layer of peat, and from modifications of the successional series in diverse geographic regions. Insensible gradations or phases due to variations in composition of plant remains set a limit to the most refined botanical division of peat materials that can be recognized.

Investigators approaching peat-land problems for the first time are apt to be influenced by the idea of permanence and fixity of specific limits. In a large measure this may be accounted for by the fact that the very recognition of such a thing as a type of peat material carries with it the impression of an entity, and that, if these characteristics are modified or supplanted by others, the unit in question no longer belongs to that type. The degree of individual difference admissible within a type is a matter of individual judgment. Variations exist within specific limits, but what these limits are is still a matter of diverse and constantly changing opinion, until these gradations and phases are measurably well established. No evidence of this sort of peat type limitation is available as yet, but the detailed application of ecological and instrumental methods strengthens the conviction that the

arrangement and naming of the different types of peat are merely matters of practice in field work.

In this paper it is not the intention to furnish the numerous details necessary to a knowledge of the different types of peat material, nor is it necessary to review from a voluminous European literature all the widely scattered observations on types of peat and their variations. So far as observations indicate, variations of stratigraphic units represent but a temporary condition. The structural development of a peat deposit is characterized by the regular occurrence of several types of peat material in many different forms and phases, such as differences in the growth and evolution of vegetation units. These phases are connected by more or less constant field relations. Unquestionably many so-called ecological stages represent merely fragments in the development of a peat deposit, reactions of one plant population upon another. On the other hand, well distinguished types of peat material will not only keep their position, but will receive a much more nearly complete and sharper definition than they have at present. It is for these reasons that only major divisions of plant remains are distinguished in the following discussion. They have been adopted also wherever the differences of information are sufficient to occasion difficulty in applying a uniform classification of types of peat. The list has been summarized (5), and has been utilized with the addition of two new marsh types of peat found in Florida and California respectively, to facilitate reference between the cross-sections of peat deposits and the text.

The conventional signs represented in the graphic illustrations of the profile sections described in large part are adjusted to the standard of European workers and the requirements of cartography. The departures which arise (partially from the inaptness of the material as a type of peat) have been stated in the legend, and in connection with each layer described in the text. Beds or strata which are not sharply defined in a deposit may be recognized by the dotted boundary lines.

It is to the interest of a group of scientific and industrial workers that coordinated efforts should be brought to the solution of peat-land problems. To those who desire general field information

regarding types of plant remains the following are some of the localities near which layers of peat material are displayed in typical form at or somewhat below the surface of the peat deposit. Macerated and colloidal types in Cedar Lake near Fremont, Indiana (fig. 2); *Phragmites* type and *Carex* type near reservoir on New Haven Marsh, Plymouth, Ohio; *Hypnum* type in Algoma Muskeag near Roseau, Minnesota, and in basal layer of the peat deposit exposed along the barge canal and James Street bridge below Rome, New York; *Cladium* type in the Florida Everglades at Okelanta and vicinity; *Scirpus* type at Middle River and near Wintersburg, California; *Sphagnum* type on Cranberry Island at Buckeye Lake, Ohio (fig. 3), and in peat deposits west of Arlberg, Minnesota; coniferous forest types near Kent, Ohio (fig. 10), and north of Kelliher and Warroad, Minnesota; mixed deciduous forest litter type in Dismal Swamp, Virginia, in basal forest of Kankakee Marsh near Crumstown and South Bend, Indiana, and in middle and upper forest beds of the peat deposit southwest of Rome, New York; deciduous forest type near Mantua, Ohio (fig. 12). More specific information concerning peat materials and their agricultural and industrial value may be obtained in Bulletin 802 (**5**).

I. Water-laid peat deposits.

The chief feature of the group of water-laid peat deposits is the presence of aquatic types of peat material as the initial layer. The deposits may vary widely in the number and character of the initial stages, and the number of stages may range from one layer to several in the deeper deposits, including secondary phases. From the manner in which the peat materials are laid down in standing or in flowing water, in fresh or in brackish and saline water, the successive layers as a rule furnish conclusive evidence of three major series of stratigraphic differences. The group of water-laid peat deposits may be subdivided into (1) basin deposits with standing water level, such as lake and pond deposits, and (2) deposits in depressions with fluctuating water level, the river and overflow deposits, of which the Florida Everglades and their alternation of fibrous and macerated layers of peat material are

a notable example. The coastal river and estuarine peat-lands merge into the (3) marine deposits such as tidal marsh and mangrove swamps. A discussion of the brackish and salt water deposits is reserved for a future paper.

Evidence of climatic changes

It might seem that the water-laid group of peat deposits could not offer reliable and direct criteria for evaluating age or time correlations, since water in basins constitutes a fairly uniform environment. There is continuity in the sequence of strata of plant remains, but macerated and more or less structureless layers of peat material bear no fixed relation to the plant populations which succeeded each other in the development of the deposit. The organic fragments are derived from many sources, and are in large part from suspended débris. Nevertheless, inferential evidence of past vegetation units and climatic changes may occur in abundance.

The evidence for age and for climatic correlations is of several kinds, of which one form is represented in the scattering and mixing of leaves, pollen, and seeds blown into a peat deposit or washed in from adjacent land vegetation units. The latest substantial comparison between plant remains (such as the pollen of conifers) in layers of peat material and the changes in climate and in the composition of land-plant communities is the quantitative method employed by VON POST (24).

A second kind of evidence of climatic changes found in peat deposits consists of dark colored, partly macerated, and fibrous layers of material alternating with predominantly finely fibrous, coarsely fibrous, or woody plant remains. The close association of this kind of stratification in practically all sorts of peat deposits, without any close relation to topography or the influence of animal agencies, appears to signify alternating wet and dry environmental conditions. Quite frequently the dark colored, partly fibrous layer of peat material is referred to by American writers as "well decomposed peat." Although it bears a striking superficial resemblance to a finer texture, similar to weathered surface material, a layer of this character does not imply conditions of aeration, or of warmth

and dryness by means of which decomposition and oxidation are accomplished. The layer represents rather the open scattered growth of plant populations, such as sedges, reeds, rushes, and brown mosses. The "well decomposed" débris as a rule is the intermixture of macerated material from aquatic and amphibious plants. The presence of diatoms, sponge spicules, shells, silt, and windblown material of various kinds usually shows that the chief condition for its formation is a higher water level. So long as the water table continues at a higher level, the fibrous type of peat tends to retain the aquatic admixture; the disappearance of the macerated débris would indicate conditions of ground water below the surface soil; and an alternating sequence of these layers would mark a period of climatic pulsation, of alternating wet and dry conditions. In carrying out quantitative determinations on samples of "well or partly decomposed" peat materials, the use of the colloidal suspension test and the methods of KÖNIG (15), MELIN and ODÉN (22), and KEPPELER (13) are only partly adequate. The possibility of obtaining erroneous results must be checked by a preliminary microscopic examination of the organic material, and by a consideration of its position in the profile structure of the deposit.

Some European workers are strongly of the opinion that a climatic break in the waning portion of the glacial period is indicated by the remains of forests found buried in stratified peat deposits, and by the "horizon" layer between the lower, in part disintegrated, and the upper, relatively more recent sphagnum peat of certain high moors. The materials are believed to be evidence showing there has not been merely a steady amelioration of climate since the last ice movement, but rather a fluctuation between periods of dry and wet climatic conditions. The dissent from this interpretation on the part of other investigators does not appear to be chiefly a matter of the proper terms to apply to types of peat and their variations. These layers of "horizon" peat and of buried forest, however, constitute more properly supra-aquatic types of plant remains, and on that account their consideration is deferred to the section dealing with the general stratigraphic features of lacustrine deposits of peat. In this connection it is suggested that

superimposed layers of colloidal type of peat material in certain deposits probably indicate another kind of evidence of former relatively dry and warm climatic conditions.

A third form of evidence which may aid in the interpretation of the age of deposits and the climate which characterized their development consists in the seams of clay found between layers of peat material. These are often found with an admixture of organic matter, but rarely laminated in a manner similar to the seasonally laminated glacial clays described by DE GEER (10) and SAURAMO (32). Interstitial clay seams appear to be coincident with the earlier portion of the Wisconsin group of moraines. They have been noted especially in connection with peat deposits located in areas where readvances of the ice sheet are displayed in the drift. The investigations, however, are not sufficiently extensive to show whether the clay seams would be prominent also in morainal systems which are free from a surface cover of wind-blown loess.

The fourth form of evidence which seems very promising is that of the marked structural differences found in certain peat deposits over a wide extent of country in which a series of moraine systems is the time factor of distinction (fig. 1). LEVERETT (19) has shown that the Wisconsin drift displays moraines which are distinctive and well preserved. They are more or less concentrated in groups which permit of much greater detail of correlation than is possible in connection with the glacial stages in Europe (12, 18, 27).

The morainic systems of the Wisconsin ice sheet mark halting places in the recession of the ice front. They obviously represent climatic pulsations, for the evidence seems clear that the ice sheet was subject to increase or decrease in response to climatic variations. Periods of warmth during which the ice sheet retreated somewhat rapidly, leaving nearly level tracts of drift, must have alternated with periods in which the climate ceased to be mild, and either remained nearly uniformly colder for a time or else reverted toward the conditions which induce glaciation.

For the study of past climatic changes and plant migration since the culmination of the last stage of glaciation, a comparison of the stratigraphic features of peat deposits should bring out evidence of great value. By actual test borings of peat deposits

within the area of the several great morainic systems, such as the Shelbyville, the Bloomington, the Valparaiso-Kalamazoo-Mississinawa, the Lake Border–Defiance, and the Port Huron, it should

FIG. 1.—Diagrammatic outline of Wisconsin ice border at several successive positions (after LEVERETT and TAYLOR **19** with slight modification): lines of direction of ice movement omitted from original map, and names of a few localities with peat deposits added by writer.

be possible to sum up the whole series of climatic changes which have taken place while the ice field receded, and to estimate the length of time for every single glacial substage. Primarily because

of their greater age, the deposits of the earlier morainic fields constitute climatic indicators of the greatest interest, and they should not only furnish additional data, but also serve as a check upon any evidence which the peat deposits in the later morainic areas may contribute.

The material here presented is only of preliminary import. It has emerged in the field work of the past seven years, and hence a definite correlation is impossible as yet, partly because too little is known of the extent and intensity of the changes. The chief difficulty, however, lies in the fact that much along the line of detailed field and laboratory studies has still to be accumulated. The conclusion is irresistible, however, that when the field is traversed the peat deposits will be found to furnish a new great record of the vegetational and climatic history of the country since Pleistocene times.

General stratigraphic features in water-laid peat deposits

The question of the formation of lacustrine peat deposits has produced a copious literature in many countries, but there is still a dearth of observational evidence on their actual structural origin. Hardly a case exists of an intensive study in which conclusive proof is available showing the types of peat material in process of formation. This does not mean that the process may not be as is generally assumed, but it does indicate that even a well-nigh universal opinion may yet constitute merely an excellent working hypothesis. It can be accepted definitely only after more rigorous tests and extensive field work disclose a clearly defined basis. This account merely serves to emphasize what may be regarded as a general view of the development and structure of lacustrine peat deposits. Although this has been discussed at some length in various papers already published, a brief outline is presented here in order to connect it with the profile sections of the peat deposits on which these discussions have a bearing. The cross-sections which follow have been selected from American and European peat deposits largely on account of their stratigraphic relationship. They visualize the succession of strata in water-laid deposits, and illus-

trate the general development which had come to the final stage possible under the limits of the particular field conditions of different countries.

In a consideration of basined deposits or moors it should be kept in mind that depressions with standing water originate in a great variety of ways (30). Of chief importance, however, is the fact that the initial types of peat material are primarily water-laid. They are largely confined to the lower or deeper parts of the depression, where planktonic organisms, together with comminuted fragments and other plant remains from both land and aquatic vegetation, sink to the bottom. A complete filling of lake and pond basins does not usually occur by the formation of aquatic types of peat material. The peat-land near Fremont, Indiana

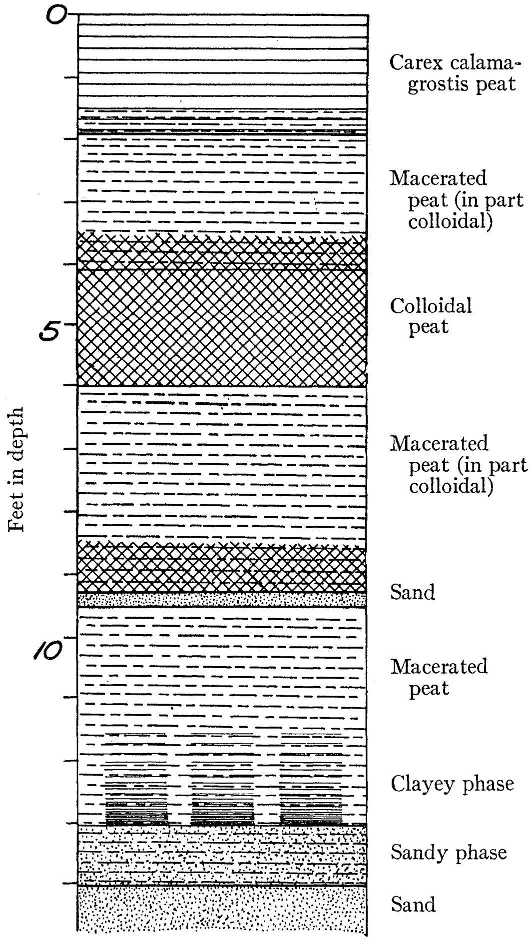

FIG. 2.—Cross-section of soundings in "Cedar Lake" peat deposit near Fremont, Steuben County, Indiana.

(fig. 2), represents a relatively rare deposit of peat. The level where the higher plant communities can gain a foothold or succeed one another depends upon the ability of the plants to form a

floating mat. The thickness of purely allochthonous (transported to the place of occurrence) layers of peat, therefore, is far less extensive than might be assumed, partly also because submerged and amphibious plant populations can take root in depths varying from 10 to 15 feet (3–4.5 m.) and accumulate as peat in situ. The macerated type of peat is nevertheless preeminent, and it varies least in character under conditions which give rise to water colored brown from the presence of suspended and dissolved organic débris. On account of the decrease in light and heat available, and the consequent absence of submersed plant communities, the filling of the depression is chiefly from vegetation units bordering the basin. The colloidal and doppleritic types of peat, on the other hand, make clear another set of conditions; they appear to indicate a higher calcium carbonate content of the waters at the time of their formation, and stimulating environmental conditions of temperature and light, in which the growth of aquatic vegetation units and planktonic organisms probably reached unprecedented proportions. There are reasons for concluding that the colloidal and doppleritic types of peat may represent another kind of evidence of climatic fluctuations. In the deposit near Fremont, Indiana (fig. 2), for example, colloidal material alternates with layers of macerated and "acidic" plant remains. The formation of colloidal material, therefore, may correspond in time with conditions of drought, when the lake or pond waters were concentrated by evaporation and became alkaline as concentration progressed. It is quite probable that the finer calcareous material in the drift had been removed by leaching, and produced variations in the chemical composition of the lake and ground waters. The calcium carbonate content when separating in the open water in a finely divided state must have become mingled with the plant débris so as to form a flocculation product and in places an end product of plant disintegration combined with lime. The climatic changes which brought about this condition may not have been sudden or excessive, but probably were oscillations of moderate intensity, whose cumulative effects were felt during that period of time.

The rate of building up a peat deposit in lakes or ponds appears to increase considerably as a plant population such as that formed by sedges pushes out from the shores, becomes nearly or quite

closed and exclusive, and forms a floating mat. Essentially this mat is fibrous and contains macerated débris. When only partially attached at the sides or beneath the surface, and if for any cause there is a considerable rise of the water surface, the mat floats upon a pocket of water (fig. 3). Later the mat is compact enough to bear the weight of shrubs, trees, and even of dense forests. When, however, the weight of the floating mat becomes too great, it either breaks or sinks with its load. Layers of marsh, shrub, or forest types of peat material then occur, interpolated between layers of aquatic plant remains. Thus an inverted order of superposition results. It would obviously be a fallacy to correlate stratification of this kind with alternating dry and wet climatic periods. Neither would the profile indicate conversion such as may result from artificial causes which obstruct drainage, nor a backward sequence of plant communities, that is, retrogression.

It is apparent also that in the gradual closing of basined

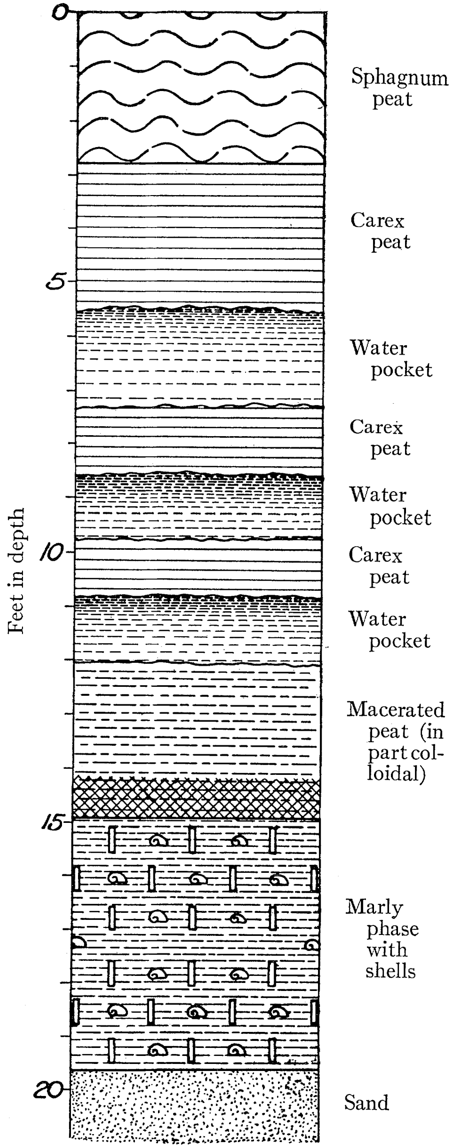

FIG. 3.—Profile section of "Cranberry Island" peat deposit at Buckeye Lake, Licking County, Ohio: elevation 892 feet a.t.; location of sounding near former experiment station (see fig. 4, BOT. GAZ. **52**: 25. 1911); a dike was built in 1838 which raised the water level 8 feet.

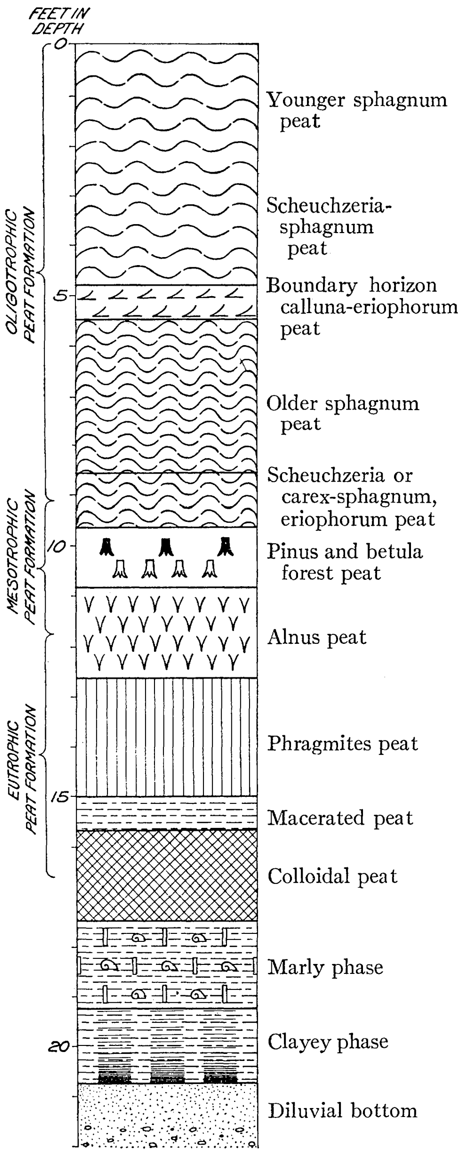

FIG. 4.—Generalized section through North German peat deposit 7 m. (22 feet) in thickness, showing succession of layers of peat material; after WEBER (36).

water by vegetation units there is not only a gradual decrease in available ground water, but in mineral food constituents as well. The earlier plant communities and those which occupy a position near the margin of the basin derive their salts from the water or from the soil on which they grow. For the succeeding units this becomes less and less in amount. When completely filled, the inward sequence of peat material (the horizontal section) and the upward sequence or vertical section of plant remains may show characteristics successively distinct in content of mineral matter, such as lime, and of water incident to the increase of thickness of peat. The difference between the total mineral content of a peat deposit and an adjoining lake has been shown for Cranberry Island at Buckeye Lake, Ohio (3). The term eutrophic is used by WEBER (36) for types of peat formed in water rich in mineral nutrients, and oligotrophic

for types with water poor in saline food constituents, while mesotrophic is applied to the peat materials in the intermediate stage (fig. 4).

Another significant difference lies in the fact that the final climatic vegetation unit of a particular region, for example, a deciduous forest (fig. 12) or a coniferous forest, is also the climax stage of the sequence of peat materials in lacustrine deposits. Successionally the sphagnum and heath shrub vegetation units appear to be a later stage in the structural development of peat deposits. Their superposition upon marsh or forest types of plant remains, however, is not to be considered an anomaly or an exception. The sequence stands in the same causal relation to development as is the case with other vegetation units. Here, however, it is connected with the fact that the ground waters of peat deposits in this stage of development are deficient in mineral salts, and that bog mosses absorb and retain large quantities of rain water on account of their anatomical structure. Sphagnum peat materials reach their greatest thickness in cool humid locations with abundant rainfall, and contain as a rule only little mineral matter. Theoretically the sphagnum stage in the structural development of a peat deposit should be succeeded by shrub, and finally by forest stages in the course of time. Actually this does not appear to take place, unless the layer of moss peat has been reduced in volume by disintegrating processes, and as a result becomes more permeable to ground waters. In the present state of our knowledge it is impossible to be certain that disintegration can occur without a change in climate. Thus the "horizon peat" between the lower (older) and the relatively more recent (upper) sphagnum peat in northern Germany (fig. 4) is regarded by WEBER (36) as due to a climatic change unfavorable for the growth of sphagnum mosses. VON POST (23) has corroborated this view by his work in Sweden, VAN BAREN (1) confirmed it for some of the peat deposits of the Netherlands, and ZAILER (37) verified it for the peat deposits of the Enns Valley in the Austrian Alps. The layer is assumed to indicate a long interruption of peat formation, during which the high moor was covered with *Eriophorum* and *Calluna*, and sometimes with forest. WEBER and VON POST conclude that the horizon peat

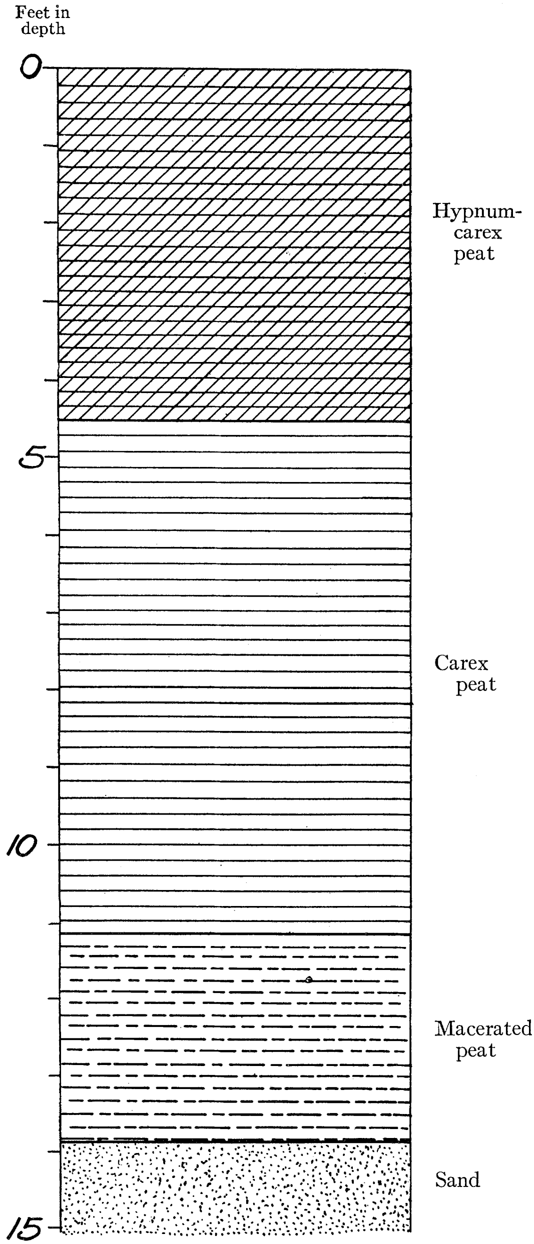

FIG. 5.—Cross-section of peat deposit near Sarna Station, Volinsk Province, Russia; after DOCTUROWSKI (8).

must have been built about the end of the later Stone Age and after the *Litorina* subsidence (33, 34). On the other hand, RAMANN (28) and POTONIÉ (25) concluded that the assumption of a change of climate is unnecessary, and that the horizon layer is determined by the physical characteristics of this type of peat. The double character of the sphagnum layer is accounted for by the gradual diminution of the water raised by capillarity during dry seasons in certain thicknesses of the peat material. "Die Sphagneen können dann nicht mehr aus den tieferen Schichten mit Wasser versorgt werden und sind auf jene Mengen angewiesen, die sie in ihrer wachsenden Schicht festzuhalten vermögen. Es werden dann zwei wasserreiche Lagen vorhanden sein, eine tiefliegende und die

Oberschicht, beide durch trockneren Torf getrennt." LESQUEREUX (16) also believed that peat deposits when checked by dryness form a parting layer between an old and a new bed of peat which takes on the shape of a dry layer.

With increasing study of the structural features of American peat deposits, correlations of various kinds will undoubtedly demand more consideration and will assume their basic importance. At present, however, it appears to be well founded to regard apparent structural climax layers as depending mainly upon the continuation of certain regional field conditions. It has already been suggested that the structural development of a peat deposit may fail to terminate on account of unfavorable local field conditions, and that various factors may inhibit a further development or may produce secondary stratigraphic features of varying character. There appears to be little doubt, however, that whenever

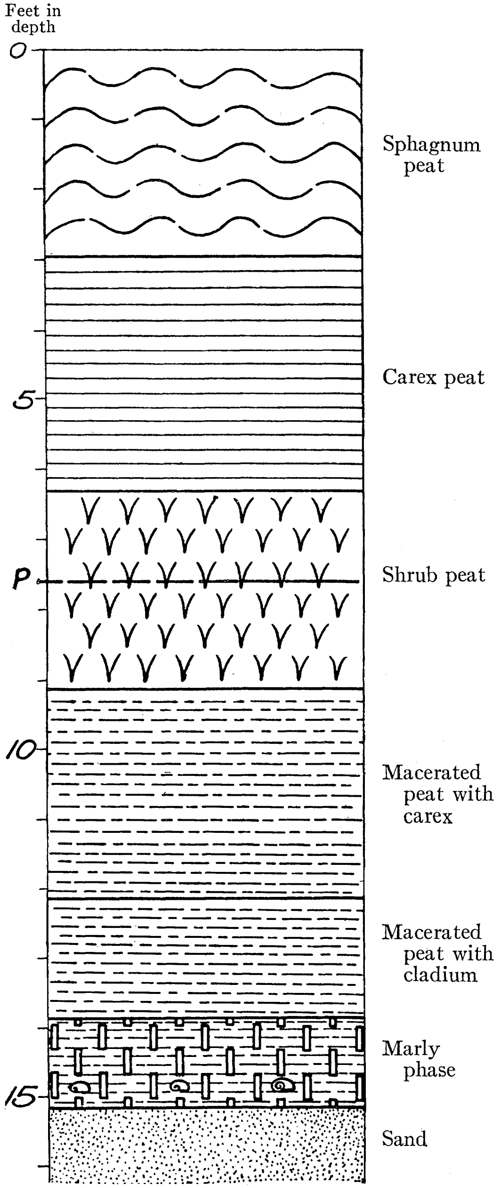

FIG. 6.—Profile section of the Åsle peat deposit, Hornborgasjön, Sweden; after SANDEGREN (31).

the movement of plant populations continues, either through a further change in habitat or in the development of new plant communities, the climatic vegetation unit is also the climax in the stratigraphic sequence of peat materials (figs. 5–7).

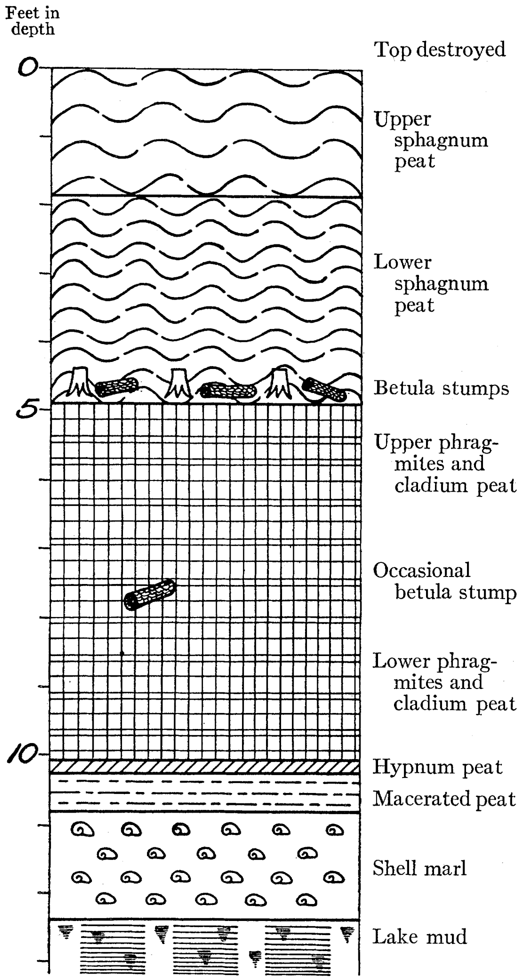

FIG. 7.—Generalized section of peat deposit of Lonsdale lacustrine moors, England; after RANKIN (29).

EVIDENCE OF CLIMATIC CHANGES IN OHIO

Peat investigations are still an unspecialized field in which the interrelation of climate, geology, and vegetation plays the paramount rôle. Whether in the service of science or of agriculture and other industries, the peat-land problem comprehends all the complex correlations of plants and their habitat; hence it should also furnish a historical perspective and the points of departure which lead to past relations. It would be presumptuous at this time to attempt to draw a parallel between the climatic changes recorded in the different peat deposits of this country. A reciprocal relation can scarcely be discovered, even in a general way, from only the few and incomplete records, and yet, although tentative, a short statement descriptive of the preliminary results obtained

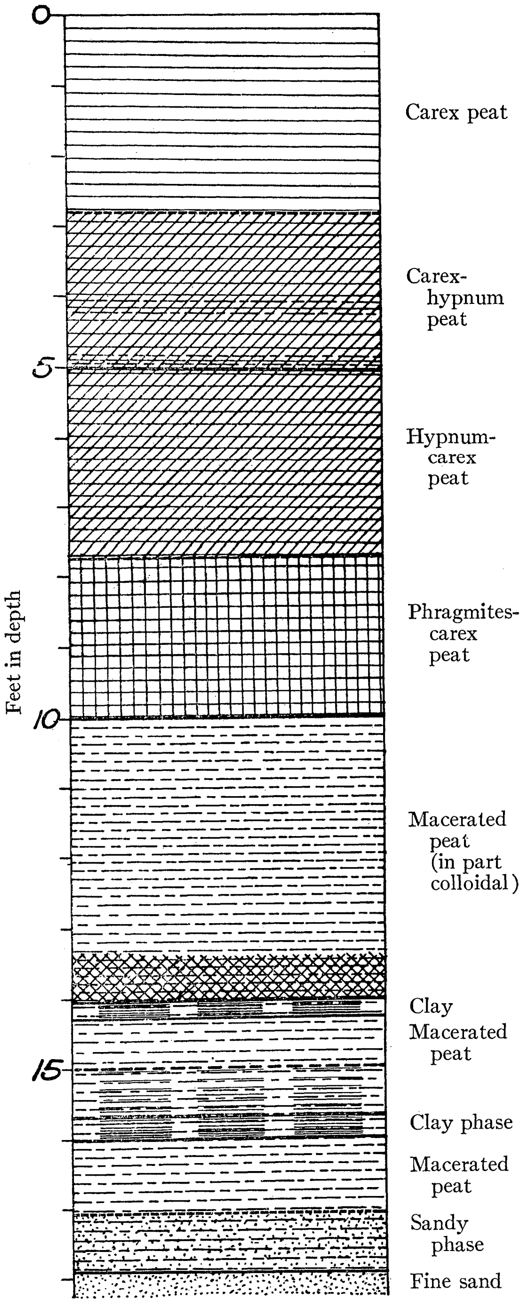

FIG. 8.—Section of peat deposit showing layers of peat material in deposit at Canton, Stark County, Ohio; elevation 1104 feet a.t.; sounding taken 300 feet south of 12th str., N.W., west side of N.O.T. car line.

may be of interest. A full correlation can be reached only by repeated efforts of this kind. Emphasis will necessarily fall upon glacial formations, because they are both an effect of climatic fluctuations and a cause in the age relation of peat deposits. The general microscopic analysis of the plant remains is reserved for a more comprehensive paper to follow.

With regard to the order of age, from older to younger, it is advantageous to compare briefly a few peat deposits (figs. 8, 10, 12) located between Canton and Cleveland, Ohio. In this part of Ohio several of the great morainic systems of the Wisconsin stage of glaciation are closely crowded together. They extend from Canton northward as a massive (interlobate) belt, and show nearly all the advantages of individual distinction

without involving the complications which occur in the broader intermorainic tracts as a result of subsequent changes in drainage. The general physical features of this area have already been described (**4**). An extended account and delineation of the geology and soils has been given by LEVERETT (**17**) and in the field operations of the United States Bureau of Soils (**20, 21**). A diagrammatic representation of the successive positions of the ice border and the location of the peat deposits is given in fig. 1.

The Canton peat deposit (fig. 8), like the Buckeye Lake deposit (fig. 3) farther southwest, is among the first and the oldest in Ohio. In both the basal layers of macerated plant remains represent accumulations of peat which probably began while the ice border was receding from its maximum position across Illinois, Indiana, and Ohio to about the limits of the Bloomington group of moraines. The growth of peat-forming vegetation in these two deposits followed soon after the recession of the ice sheet, before the drift had become drained by development of valleys on it.

Two seams of clay in the Canton deposit are noteworthy. Their positions indicate that the early period of peat formation was at least twice marked by climatic disturbances. The presence of the two layers of clay between layers of macerated types of peat seems to show that the ice readvanced to near this point into territory that had been laid bare following the maximum extension of the glaciers. In these states the western end of the Bloomington group of moraines not only overrides the weaker ridges of the Champaign moraines, but also extends into the ground occupied by the Shelbyville morainic system which was formed at the culmination of the Wisconsin stage of glaciation. The clay was probably deposited along the border of the ice mass by the same agencies that contributed the coarser material at the margin of the moraine, while further out, in the water basins, sand and finally clay were left. The deposition of clay may have taken place chiefly during the retreat of the ice front, when climatic conditions had become much warmer. It is not improbable that these clay seams represent the loess material which is known to cap the earlier morainic systems of the Wisconsin drift. Much of the material from the loess covered plains may have been carried

up by strong winds, forming at first a surface coating upon the ice at the time the moraines were developing. The effect of possible meteorological changes over wide areas, such as PENCK and others have worked out, must be borne in mind. The shifting of all climatic zones southward (26), caused by the general lowering of the temperature during the Ice Age and the depression of sea-level, points to the probability of this area as part of a relatively windy arid belt. After the ice had melted back some distance, the inorganic material may thus have come to be contributed to the peat deposit.

The basal layer of macerated peat is somewhat silty, and has a rather aged appearance. It is assumed, provisionally, to have been formed during the first or Shelbyville period of deglaciation. The layer of plant remains found overlying the basal peat has a much fresher aspect, but the organic débris in both of the lower layers of peat seems to fall short of reaching the greater variety of plant fragments which occurs in the succeeding layers. Further study of a microscopic nature, however, is necessary to establish fully the character of the plant remains from each of these glacial substages. The strongest evidence of an interval between the formation of the basal macerated peat and of the overlying layer of macerated plant remains is found perhaps in a comparison of the character and amount of the uppermost seam of clay. This clay seam is much more sharply terminated than the lower one, and it is also worth noting that the upper thickness of the clay stratum is compact and relatively free from plant remains. Whether or not the evidence thus far at hand favors the view that the seam of clay is derived from wind blown loess rather than from drift, or differences in the strength of the outwash, of considerably greater significance is the fact that the upper mineral layer constitutes a distinct break in peat formation. The cause of this break in the succession of peat materials must evidently have been a change from colder climatic conditions, from a more or less notable readvance, and a renewed aggression of the ice sheet.

Apparently the climate was undergoing amelioration at the time, probably giving rise also to a lower water table. That such oscillations have occurred is evident from the work of LEVERETT

and others. A certain degree of aridity seems to have prevailed, not only during the withdrawal of the ice, but up to the period which resulted in the formation of the Bloomington morainic system. The Bloomington period of peat formation was stopped by the upper seam of clay. This suggested correlation appears to be correct, for the upper clay layer can be connected closely with that part of the Valparaiso-Kalamazoo-Mississinawa morainic system which passes northeast of Canton through Portage County. The principle members of this group of moraines show west of here a marked differentiation of glacial lobes and a shifting of the lines of axial ice movements. The glaciers, as shown by the studies particularly of LEVERETT and others, encroached again over the surface of land that had been vacated by the earlier recession of the ice border. This readvance, the limits of which are marked by a morainal belt reaching from eastern Illinois and extending northward into Michigan to the vicinity of Kalamazoo and Battle Creek, has usually been designated the late Wisconsin stage. It covers a time of drift deposition reaching to the series of generally weak moraines which are included in the Lake Border-Defiance system.

During the time which elapsed while this ice front receded, and which may tentatively be called the Mississinawa glacial substage, the third tier of macerated peat was formed and probably also some of the superposed layers of fibrous plant remains. There is hardly any feature in the structure of the Canton deposit so conspicuous as the fibrous layers of peat, which rest on and in places grade into the underlying third basal bed of macerated organic material. The *Carex* and *Phragmites* plant populations, from which these layers of relatively coarse fibrous peat are derived, appear to have grown at ground water levels much lower than those which prevailed at later glacial substages. The uppermost beds of fibrous peat of more recent development contain an admixture of aquatic plant débris. They do not represent in their texture the features which would be characteristic of a gradual decrease in available ground water coincident with the closing of water basins by vegetation.

In the absence of more definite correlations, these three primary series of peat layers, namely, the several basal layers of macerated plant remains, the middle bed of coarsely fibrous peat, and the

upper layers of partly fibrous plant components, might be interpreted as representing three great changes in water level. They

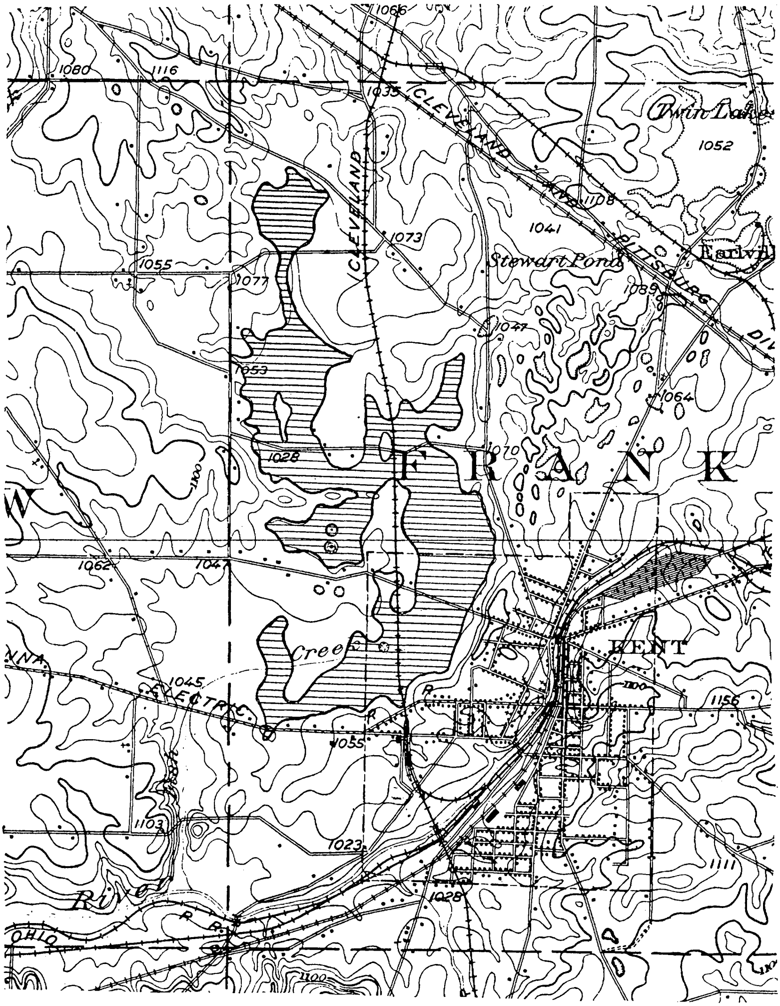

FIG. 9.—Location of peat deposit near Kent, Portage County, Ohio, and of sounding illustrated in fig. 10; scale, 1 inch = 1 mile (2.5 cm. = 1.6 km.).

may correspond, therefore, to three climatic stages that left their traces in the structure of the Canton deposit. From this it would seem that a comparatively warm period with moderately humid

conditions must have been preceded and followed by two comparatively cool periods, characterized by changes between drought and wetness greater in degree than seasonal variations. For this interpretation, however, a series of various facts is doubtless required. A consideration of the structural appearance of the deposits in line north of Canton should give more adequate evidence of such alterations. They represent in part a contemporaneous and later age of peat formation which should bring into clearer perspective the probable climatic conditions during and after the close of the third glacial substage.

The recession of the ice front marked by the Valparaiso-Kalamazoo-Mississinawa morainic system to near the border of the Huron and Erie basins initiated the development of the Kent (fig. 10) and the Mantua peat deposits (fig. 12) in the order named. An examination of the profile sections suggests a long interval of peat accumulation. In about the middle of the Kent deposit there is evidence that here also an unusual disturbance had affected the course of peat formation, and that a well marked climatic change had occurred. The position of the layer of forest peat in the Kent deposit suggests that the change is contemporaneous with the deposition of the Lake Border-Defiance system.

At the bottom of the Kent deposit, overlying the bowlder clay, are shells of fresh water mollusks, and above them a layer of plant remains from aquatic vegetation. This is followed by macerated material, a part of which is distinctly gelatinous. The upper portion of the structureless débris merges into a layer of fibrous plant remains, showing that a mat of sedges and other marsh plants had covered the basin. When this stratum was formed, a mixed deciduous but predominantly coniferous forest appears to have been growing on the borders of the basin, which gradually encroached and finally occupied the entire peat-land area. The thickness of the layer of forest litter shows that the ground water level at that time was below the surface soil, and that the tract remained moderately moist for a considerable period of time.

It can scarcely be decided in the present state of investigation whether or not the end of the Mississinawa glacial substage was accompanied by a widespread dispersal of forest trees from south-

eastern portions of the United States. The first coarsely fibrous layers of *Carex-Phragmites* peat in the Canton deposit, and especially the middle forest bed of the Kent deposit, certainly have a suggestive feature of resemblance. Among land-laid peat deposits, the basal forest bed in the Kankakee Marsh near South Bend, Indiana, appears to indicate a corresponding time relationship, the climatic conditions of which favored forest associations more distinctly southern in range. Layers of coarse, fibrous peat material and of forest peat seem to offer the evidence of a prolonged warm period, during which migration of deciduous shrub and forest vegetation units might readily have taken place to areas considerably more northward than they are at the present time (14). From these facts there appears some support for the suggestion that the probable range in temperature and precipitation as well as the duration of this warm period made it possible for many trees

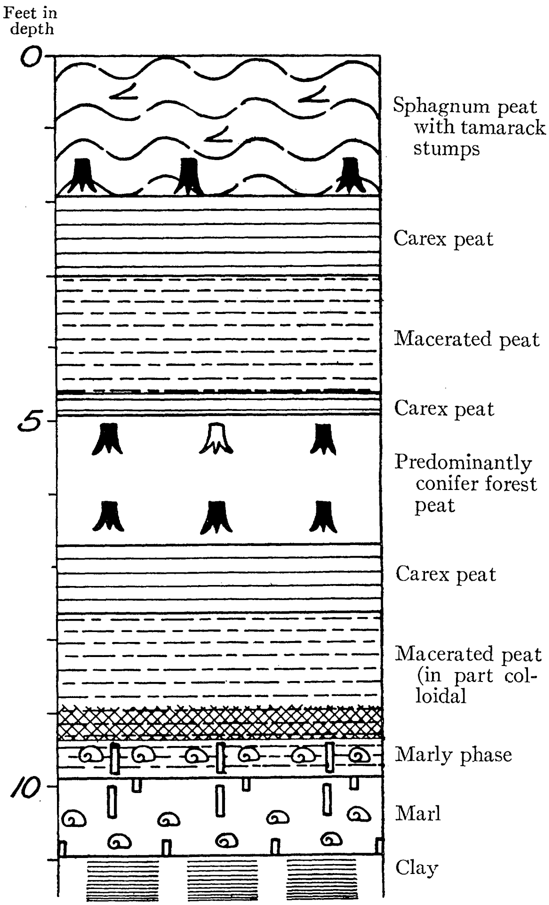

FIG. 10.—Cross-section showing structure of peat deposit near Kent, Portage County, Ohio; elevation 1028 feet a.t.; location of sounding indicated on map (fig. 9).

and shrubs to extend rapidly the limits of their distribution. It is unwise, however, to venture more, since at the present time definite stratigraphic and botanical data from peat deposits of northern states have not been exhaustively studied, nor have the investigations of the later quaternary deposits of the eastern and southern coastal states been carried to a point where they could be definitely correlated with the peat beds of this glacial substage.

There followed a wet period, during which the forest in the Kent deposit seems to have become submerged. The weight of the trees can scarcely have caused a sinking of the forest layer in this basin, since its depth is small and the underlying layers of peat material show no compression or disturbance. With the rise of the water table a layer of fibrous material from sedges and various other marsh plants began to accumulate above the forest stratum, but there soon followed a more rapid increase in the water level. The area became covered for a time with water.

The period of change recorded so conspicuously in the Kent deposit appears to be associated with the Lake Border glacial substage. It is readily correlated with the time which elapsed when the front of the Erie lobe receded northward to the Port Huron morainic system. As the ice in its retreat uncovered the Ohio divide, inundation followed the escape of waters from the subsequent melting of the ice masses. No clay, however, entered into the formation of the peat deposit. The Lake Border moraines are practically free from loesslike silts, and apparently they were not strong enough to spread a seam of clay over this basin. When peat accumulation recommenced, there was again formed a layer of macerated material, followed by a fibrous type of peat from sedges, above which appears a stratum showing small twigs and branches of shrubs. Once more the area had become cool and dry, too severe perhaps for the free spreading of forests. Probably many tree species were again driven southward and replaced by more open vegetation, such as grassy marsh and shrubs. This cool period meliorated in severity rather rapidly and became sufficiently temperate for forests, for in the uppermost layer of peat are the remains of tamarack (*Larix* sp.). The stumps of the trees are standing in the peat itself. The present surface vegetation is a dense stand

of tamarack. In the partially wooded portion grow heaths such as *Cassandra* (*Chamaedaphne*) sp., *Vaccinium corymbosum*, and others, while the ground cover consists largely of sphagnum mosses with the cranberry and similar plants characteristic of sphagnum bogs. The southern portion of this tract is under cultivation.

Turning to the Canton peat deposit, it is interesting to note that the middle forest layer is wanting in this deep basin. The type of peat material of the period contemporaneous with the Kent middle forest layer consists of fibrous and relatively coarse plant remains from sedges and to some extent from reeds. The quantity of water must have diminished independently of the local alterations in the water table, for layers of a fibrous texture accumulate only under moderately moist conditions. The overlying peat stratum, on the other hand, is formed from *Hypnum* mosses and sedges, and has an admixture of macerated débris, clearly showing the advent of a cool period.

The succeeding layers in the Canton deposit show a gradual elimination of the *Hypnum* mosses as a peat forming component, and they also indicate a return of atmospheric conditions swinging toward a warmer climate. Before its cultivation the Canton area is reported to have been a marsh with the margins partly forested. Thus the uppermost layers of peat in the two deposits seem to show that during their later history, from the last glacial substage (the Port Huron time and the Lake Champlain period) to the present, the amelioration of climate has been relatively more steady than at any time since the culmination of the Wisconsin period. The lack of structural diversity is related probably to the distance of these deposits from the direct influence of the later glacial substages.

The beginning of the Mantua peat deposit (fig. 12), it is reasonable to infer, dates from the period of accumulation of *Hypnum* mosses in the Canton peat deposit and the submergence of the forest layer in the Kent deposit. In the Mantua deposit the uppermost layers similarly point to the supplanting of a cool by a more temperate period of climatic conditions, and to the migration of plants as an essential process in the sequence of peat materials. It is worth noting that the forest layer has the stumps of tamarack

(*Larix* sp.) in the lower portion of the stratum; while those of maple (*Acer* sp.), ash (*Fraxinus* sp.), and elm (*Ulmus* sp.) are found in the forest litter nearer the surface. The degree of natural drainage which established itself in time on the surface layers of this deposit determined, probably in large part, the character of the succeeding vegetation cover. Deciduous trees such as the red

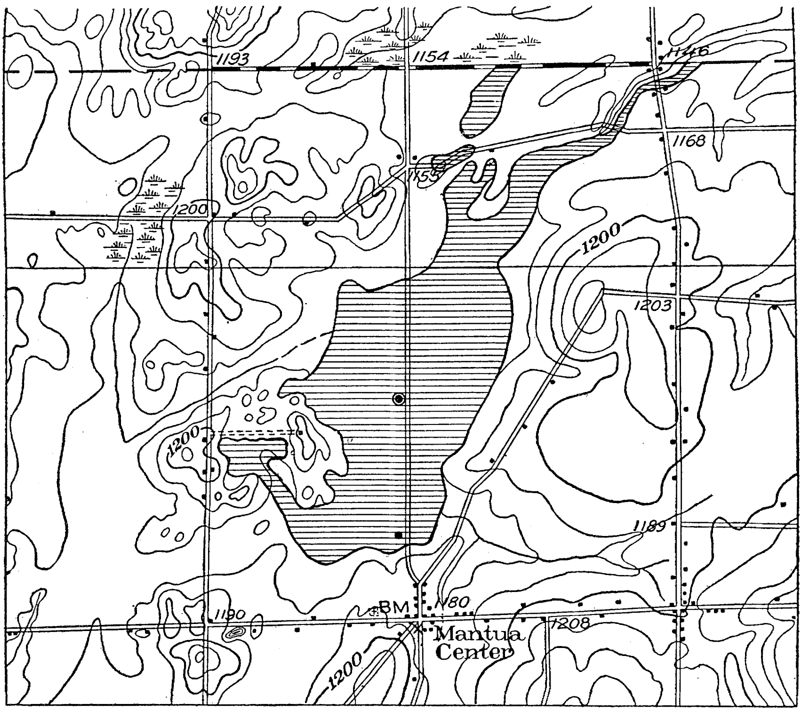

FIG. 11.—Location of peat deposit near Mantua, Portage County, Ohio, and of sounding on lot no. 9 illustrated in fig. 12; scale, 1 inch = 1 mile (2.5 cm. = 1.6 km.).

maple, black ash, and elm are still the dominant trees in the present surface vegetation of this tract of peat-land. Here again it is obvious that much is not yet clear about the major changes of climate until quite recent times, and that more extended and more critical field studies are required upon northern deposits which admit of ready comparison with the older peat accumulations. These questions of climatic changes from the later glacial sub-

stages to the present are critically important, for they bear radically on interpretations that have already been well supported in the countries of northern Europe.

It does not lie within the sphere of this paper to review the literature dealing with the probable causes which produced the glacial period or its climatic changes. These and other considerations are discussed fully by CLEMENTS (3), DOUGLASS (9), HUNTINGTON (11), and others. The only question is how far the types of peat material and their sequence in peat deposits may furnish evidence of climatic effects during the successively less extensive positions of the ice border. The facts given in this article seem to indicate at least three if not four major oscillations during which the climate fluctuated between warm and cold conditions, between periods of greater dryness and greater humidity.

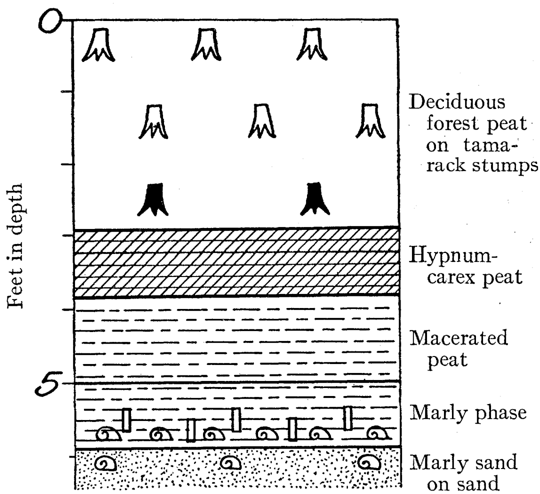

FIG. 12.—Profile section showing sequence of strata in peat deposit near Mantua, Portage County, Ohio; elevation 1155 feet a.t.; sounding on lot no. 9, west side of Center Road, as indicated on map (fig. 11).

Summarizing the climatic changes since the disappearance of the Wisconsin ice sheet in Ohio, the following may be stated tentatively: In the record of a few Ohio peat deposits an irregular series of changes can be traced, due to effects of climatic influences. Apparently twice a comparatively dry and cool period alternated with a relatively warm and humid period. After glaciation had reached its maximum extension, there followed two minor periods of recession of the ice field, a time during which a cool and dry climate bordered closely the glacial regions in this locality.

It was probably a period of winds, cooled from the ice sheet, and of loess deposition. The accumulation of drifted, wind-blown sand in the Kankakee, Indiana, area, portions of which were later covered by peat materials from a basal forest, may be referable to the first two glacial substages. In the general shifting of climatic belts the cold climate along the border of the retreating ice probably passed into dry windy conditions. On the exposed ground-till only marsh plants and low shrubs may have been the dominant plant population. This period of relative aridity in turn gave place to a second great advance of ice, the late Wisconsin, probably not of as great severity as the first, after which a prolonged warm and somewhat humid climate prevailed. This appears to have been the period of invasion and wide dispersal of forest trees from the south, and of a more northerly distribution of certain species than is now recorded for them. As to the end of the late glacial time, the climatic characteristics from the last glacial recessions to post glacial and present conditions stand as yet considerably ill defined. The evidences indicate periods during which the climatic zones shifted again somewhat. There appears to have been a return to cooler and drier climatic conditions, followed by a temperate and more humid period than exists at the present time in the same localities. The present period is probably approaching a climate of rising temperatures and (or) decreasing precipitation. The botanical data, however, are as yet insufficient to permit more definite conclusions, and they are wholly inadequate for drawing a parallel between the past climatic conditions of different countries.

The writer has had considerable hesitation in publishing the climatic correlations for the peat deposits of these great morainic systems. Although the interpretation accounts for a series of facts that are in need of being formulated, yet there might perhaps be another way of correlating the field observations. For this, however, the work of several years will doubtless be required. This preliminary paper may aid in the meantime a field of peat investigations to which BLYTT (2), WEBER (35), and others have been among the first contributors. With these major climatic fluctuations as a basis, chronological data of considerable value may perhaps be obtained by this method of peat investigations

for several sciences, including archaeological research. In its relation to the practical worker in peat-land problems it is hoped this paper will suggest the influence which structural differences in peat deposits necessarily exert upon a true estimate of the value of peat deposits and upon the progress of peat-land utilization, especially upon the plans, methods, and equipment which must be adopted to convert suitable areas into productive sources of national wealth.

United States Department of Agriculture

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